Camera background

A Phantom 5 camera was purchased last year for use in developing the imaging needed for the Boiling eXperiment Facility (BXF) The camera, incidentally, will also is available for use in the division. This high speed digital camera (shown below) is said to be the first commercially available CMOS camera to offer rates of 1,000 pictures per second at 1024x1024 pixels.

This camera is one of the Boiling eXperiment Facility (BXF) project's more advanced electronics items, and its failure would seriously impact one of the PI experiments. The current dense electronics design used in COTS devices like this one make them more susceptible to radiation. High speed electronics devices have been observed to latchup and fail unexpectedly during on-orbit operation. Object of the radiation test was to identify the sensitivity of a Phantom V5 camera to radiation such as exists along the ISS orbit. The hope was to quantify the likelihood of a failure and be able to plan for an on-orbit workaround.

Radiation background (per JSC report)

Hardware must be able to operate in the environment for the duration of their missions. The two major elements of the ionizing radiation environment are the deposition of energy from Total Ionizing Dose (TID) and the Single Event Effects (SEE) produced by high energy particles like protons and atomically heavier ions. The TID experienced by any hardware element is a function of its location on the vehicle. Shielding values are available for various locations within the spacecraft. The SEE's experienced on orbit are not substantially mitigated by shielding because of the high energy of the particles producing the effects.

Radiation testing for SEE's with high energy protons is designed to establish the susceptibility of a given test article to trapped protons in the South Atlantic Anomaly (SAA) and heavy ions due to Galactic and Solar Cosmic Rays. A SEE can be detected as:

- **Single Event Upset (SEU) –** an event like a bit flip resulting in a data error only.
- **Functional Interrupt (FI) –** an event requiring a software reboot or a power cycle.
- **Single Event Latchup (SEL) –** an event where the device has an abnormal conduction path established by the ionizing radiation and as indicated by a primary power supply current change. Power must be recycled to regain control and/or to save the device from destruction.
- **Single Event Burnout (SEB) –** an event where the device has an abnormal conduction path established by the ionizing radiation and is destroyed almost immediately.

The occurrence of a SEE is a single sample observed from a random process. The more samples (in this case SEE's detected) observed, the better the estimate of the Mean Time Between Failures (MTBF) for that specific type of SEE. The goals of this testing are to establish estimates of the MTBF's for each type of SEE detected for a given test article or electronic component.

The probability of an SEE occurring within a test article is related to the number of particles per square centimeter (called fluence) allowed to impinge on the device. The general criterion used in testing with protons is to expose each beam position or test article to a fluence of 10 billion (1E10) protons/cm2.

Even though the SEE susceptibilities measured during testing are only from proton testing, the MTBF's cited in JSC's reports are the composite MTBF's due to the nominal proton (primarily SAA trapped protons) and the nominal heavy ion (Galactic Cosmic Rays) environments.

<u>Test description</u>
The camera was mounted as shown in the Indiana University Cyclotron Facility. Their Radiation Effects Research Program, RERP, makes available proton and other light ion beams to industry, university and government users for simulation of the space radiation environment, studies of single event and other radiation effects in microelectronic devices and investigations of nuclear radiation effects on optical sensors, opto-electronic and other radiation sensitive components.

The plan was to use the camera in a typical operation while radiating the electronics components from the camera's side with the beam with a level equivalent to a 10 year dose of heavy particles. Beam shape was 2 inch x 2.25 inch after passing through a copper vignette and the beam was expected to be pointed at an array of six side locations (a grid of three horizontal locations by two vertical locations) in addition to the location of the CMOS sensor. Only the first three positions were radiated before the tests were stopped due to the camera failure to communicate with its control laptop (located in the control room).

Test results

This specific test camera (supplied by Vision Research) was tested last November in the University of Indiana's radiation facility in Bloomington, Indiana. Standard JSC program testing (simulated 10 year operation) was done. After Vision Research received the radiated Phantom v5 back from Indiana, they performed a careful autopsy to determine what failed. They noted that the Phantom v5's firmware resides in a toshiba flash chip on the timing board (which is in the middle of the stack of boards) and that the firmware is loaded into a fpga thru a microprocessor when the camera boots. The camera died while it was operating, which would infer that the fpga lost all or part of its programming. The fact that we could not reboot the camera implies that the toshiba flash chip (which holds the firmware) lost all or part of its program. After the autopsy, the firmware was reloaded into the toshiba flash chip and the camera functioned properly. The workaround, assuming that we control the v4 or v5 via an RS232 serial link, would be to write a c+ routine to accomplish this. The firmware for both the v4 and v5 is loaded by the serial link, and there are supposedly three programming "steps" involved in order to reload the camera's firmware. Two of the steps involve using a "programming jumper" (installed at the 10 pin connector on the rear of the v5) or a "programming switch" (accessible under the rear cover of the v4).

Current design status

We are currently considering various high speed cameras, and expect to choose one shortly for development and likely flight use. The Phantom camera, while very good, may not be chosen due to software considerations. Its control program only runs under Microsoft Windows and the flight software is expected to be run under some real time operating system. To reduce software development time, we will likely choose a camera that can be run under that kind of operating system.